A study of technical, economic and social factors affecting micro-hydropower plants in Nepal

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***Abstract*— Due to slow expansion of the national grid, many rural areas of Nepal depend on micro-hydropower plants to provide electricity to homes and businesses. Micro-hydro turbines are designed, manufactured and installed by small and medium sized enterprises based in Nepal. After a plant is commissioned, its technical and economic operation is managed by selected members of the local community. When problems affect the plant, people are forced to rely on traditional or fossil fuel-based technologies to provide light to their homes, whilst many businesses cannot run without a supply of electricity. A study of 24 sites (18 Crossflow and 6 Pelton turbines) looked to identify the combination of technical, social and economic factors that affect the performance and reliability of plants. Interviews were carried out with plant operators, plant managers, and consumers to understand how the plant is run and managed, and the position it occupies in the local community. A quantitative assessment of maintenance and observation of 10 sub-systems was conducted at each site. The information collected demonstrated that the social and economic impact at home and in the community mean that micro-hydropower plants are highly valued. However, it was found that 40% of managers reported that monthly payments were not always sufficient to pay for repairs. By combining information on the domestic and commercial end uses, financially threatened sites have been identified. At the sites with trained operators, a higher quality of maintenance was found. Across all of the sites, problems at all sub-systems which could weaken performance and increase running costs have been identified.**

Keywords—Nepal, micro-hydropower, social, technical, economic

I. Introduction

The development of micro-hydropower in Nepal has been very successful with an estimated 3,300 micro-hydropower plants (MHPs) providing a total of 30MW of power [1]. Many of these sites are located in rural areas, long distances from the cities in Nepal where the turbines are built. MHPs are either owned collectively by the community, co-operatively or privately. In Nepal, community ownership is most common and beneficiaries provide labour during plant construction. Following commissioning, successful plant operation requires diligence from operators, managers and continued involvement from the local community who are often required to help with the repair of civil structures.

Previous research has established variability in the technical performance [2], has demonstrated maintenance practices vary depending on the end uses of electricity [3], and indicated issues with the manufacture of turbines and construction of their civil works [4]. However, with a large number of turbines in operation and with a targeted lifespan of 20 years, greater attention is required to improve the reliability and operational longevity of plants in operation. Existing research has not addressed the complex relationship between the technology and its stakeholders. Reliable plant operation is not a purely technical problem. Consumers must feel satisfied by the services that the technology provides and be content with the price that they pay. The income of the plant must be sufficient to ensure that operators and managers are paid, and enough money is available for maintenance. Operators must have the required knowledge to run the plant whilst managers need to be competent in tariff collection and bookkeeping. Without commitment from all stakeholders, plants perform poorly and fail to provide a reliable supply of electricity.

This study assessed 24 sites using a combination of qualitative and quantitative assessment and interviews with operators, managers and consumers. By combining this information, the complex relationship between the stakeholders and the technology can be analysed. This paper addresses the interaction of social, economic and technical factors that affect the success of MHPs and highlights methods to address threats to the reliability of plants.

II. Methodology

The study visited 24 sites in two districts of the Western Development Region of Nepal, 22 in Baglung district and 2 in the neighbouring district of Gulmi. Of the sites, 18 had Crossflow turbines and 6 had Pelton turbines. Baglung district, in particular, has a strong reputation for hydropower with the highest density of MHPs of any district in Nepal [5].

At each site, data was collected through observation, survey and semi-structured interview. A quantitative assessment of maintenance was made at the following sub-systems: intake, de-silting bay, canal, forebay tank, penstock, powerhouse, internal pipework, turbine, generator, control panel and generator.

This study was funded by the Cabot Institute, Bristol. J. Butchers' PhD is funded by the Engineering and Physical Sciences Research Council.
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TABLE I. MARKING SCHEME FOR DESILTING BAY

	Description	*Score*
Desilting bay	**Very well maintained. Good evidence of regular preventative maintenance.** Desilting bay is clean, free from erosion with no obvious cracks visible. Minimal silt build up.	5
	Evidence of effort to maintain the sub-system but without following a schedule closely. Some dirt, debris and a small amount of erosion is visible. Cracks may be present but they are small. Any obvious leaking is minor. Some silt is obvious in bottom of bay.	3
	Poorly maintained. Preventative maintenance is rare. Intake is heavily contaminated with obvious signs of erosion. Cracks are significant and/or leakage is obvious. Significant build up of silt in bottom of bay.	1

Each sub-system was rated using criteria for assessment developed from maintenance guidelines in the available literature [3, 6, 7]. An example for the desilting bay sub-system is shown in Table 1.

At each sub-system, observations were also recorded regarding the quality of manufacture and construction. At most sites, observations were made in the presence of an operator who provided additional verbal insight. Interviews with 24 operators, 24 managers and 23 consumers were semi-structured allowing the collection of relevant quantitative and qualitative information. Interviews were conducted in Nepali by the 6th author, a community development officer who is accustomed to working in rural areas. A more detailed explanation of the methodology can be found in [8].

III. RESULTS AND DISCUSSION

A. Domestic uses of electricity

Responses from consumers indicated their domestic electricity uses and the impact they have on their time and expenditure. Fig. 1 shows the electricity uses mentioned and the percentage of consumers using them in their homes.

Lighting and mobile phone charging were the most common domestic uses. Lighting remains the main use of electricity from MHPs since their introduction to Nepal. When problems occurred at their MHP, all of the consumers said that they

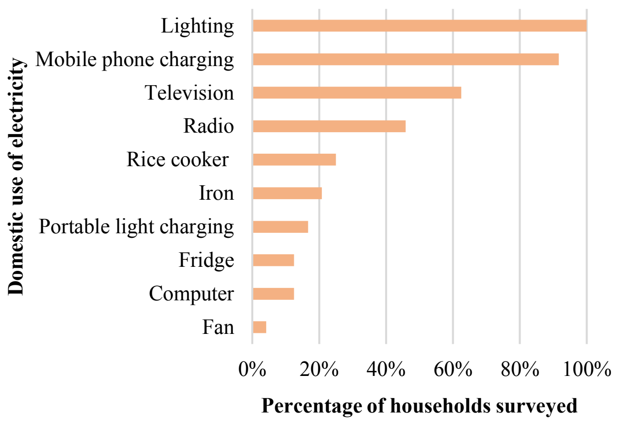

Fig. 1 Domestic uses of electricity

purchase candles or kerosene for lighting which was a greater expense than their electricity bill. Nepal, like much of the developing world, has experienced an influx of cheaper mobile phone that has resulted in a surge in their use. Mobile phone subscriptions in Nepal have increased from 1.2m in 2006 to 32.1m in 2016 [9]. For some consumers, the benefits of mobile phone charging in their own homes also saved a substantial amount of time and money. One respondent explained that they save “30 Rupees for one full charge” and avoid a journey “that takes around 45 minutes to 1 hour to reach [on foot]”. Another respondent said that without a connection to the MHP, their family would spend 900 Nepali Rupees (NPR) per month on mobile phone charging alone compared to a monthly electricity bill of NPR 150 (1 NPR is approximately $0.009). Similarly, other appliances mentioned by consumers in this study demonstrate changing behaviour in relation to energy use. A 2009 study examined electricity use by consumers connected to MHPs in Nepal; no households reported using rice cookers, fridges or computers whilst radio and television use were 3.8% and 7.6% respectively [10]. In our study, radio and television use were at 46% and 63% respectively. Whilst the 2009 study had a larger sample size and covered more districts, the increases in less than 10 years are considerable. The new uses of electricity relate both to leisure as well as time and money saving.

Consumers have become used to the benefits that connection to an MHP provides, one respondent explained that “it is difficult when the plant is shut down and creates problem even if it is off for 1 or 2 days”. When problems occur, lives are impacted both economically and socially.

B. End uses of electricity

Beyond the home, the end uses of electricity of all the sites were highly varied. Table 2 groups these end uses into 3 categories: productive uses, commercial services and community services. Productive uses included traditional agro-processing uses such as flour and grain milling, but also a range of less conventional industries including a factory for processing cotton and another for making noodles. Commercial services were dominated by shops, however, other uses included powering mobile phone masts and radio towers. Many community services were powered by hydropower plants including 84 schools, 40 hospital/health clinics and 9 community centres.

The end uses in this category demonstrate the impact that MHPs can have beyond their own community. Significant tangential benefits can be delivered in rural areas to the wider community, and not only to paying customers of a hydropower plant. Similarly, mobile phone masts powered by MHPs deliver an improvement in communication to anyone using a mobile phone in the area regardless of where they live or purchase electricity from. The benefits inside and outside the home make MHPs important institutions in their local communities and this was acknowledged by consumers.

TABLE II. END USES OF ELECTRICITY FROM 24 SITES IN NEPAL

Commercial services	*Total*		*Community services*	*Total*
Grocery shop	353		School	84
Tea shop	164		Hospital/health clinic	40
Bank/Co-operative	28		Local government office	35
Clothing shop	31		Post office	7
Hotel/Lodge	16		Community centre	9
Barber shop	9		Temple	2
Meat shop	8		*Productive end uses*	*Total*
Telecom tower	9		Flour/grain mill	85
Radio tower	5		Poultry Farm	58
Computer training centre	3		Furniture making	37
Stationary shop	3		Welding workshop	19
Irrigation pump	3		Bakery	10
Movie hall	1		Dairy shop/factory	4
Petrol pump	1		Cotton factory	1
TV cable office	1		Stone thresher	1
Workshop/Garage	1		Noodle factory	1

For 4 respondents, the micro-hydropower user's committee was regarded as an important decision making body. When asked whether they would prefer electricity from the grid, one consumer explained that it "depends on the decision of the community". Five consumers chose to describe the MHP as "local" whilst another said they would not prefer to be connected to the national grid as "much hard work [had been] done for the local level MHP plant". The locality of the plant was also perceived as an advantage in resolving problems. One respondent said it was a benefit to be able to call the operator in the event of a problem.

MHPs provide a range of benefits that make a social and economic difference to lives, both through employment opportunities and newly available services. The collective community effort exerted in developing the MHP and its integrating community structure mean it is considered not only a valuable technology but also as a socially important institution.

C. Electricity tariffs

During interviews, 3 forms of management structure were encountered; there were 2 private, 2 co-operatives and 20 community owned sites. Privately owned MHPs were run as a business with the proprietor(s) taking responsibility for management including tariff setting and financial management. In both co-operatives and community owned sites, periodic meetings allow beneficiaries to have input into decisions made regarding the MHPs and would be expected to provide labour if repairs were required. In the co-operative structure, consumers' initial labour and financial contribution give them a share in the MHP. For community owned plants, the relationship is not formalized.

Using the recorded monthly electricity cost and the tariff structure for each site, it was possible to calculate the approximate monthly electricity consumption for each consumer. The monthly electricity consumption by consumers in the study ranged from 7kWh to 60kWh with a median and mean of 15kWh and 22kWh respectively. In total, 23 of the 24 sites charged consumers based on electricity meters fitted in their homes. The one exception was a site where electricity meters were not working and a flat rate of NPR 200 was charged. At the other sites, tariffs were charged using a base rate which permitted the use of a defined number of kilowatt-hours (kWh) with additional consumption beyond this limit charged on a per unit kWh basis. The base rates varied considerably from 4kWh for NPR 100 to 20kWh for NPR 100. Table 3 shows the mean, median and range of prices calculated using the recorded tariff structures. These values have been calculated using the mean, median and range of estimated monthly energy consumption.

TABLE III. PRICES FOR VARYING LEVELS OF ELECTRICITY CONSUMPTION

Estimated monthly consumption (kWh)	Minimum price (NPR)	Mean price (NPR)	Median price (NPR)	Maximum price (NPR)
7 (minimum)	50	108	100	200
15 (median)	100	135	120	225
22 (mean)	116	190	176	330
60 (maximum)	200	510	492	900

The difference between the cheapest and most expensive electricity bills is at least a factor of 2 resulting in a large difference in both the income between MHPs and financial pressure on its consumers. Interviews revealed that during each month, employees from every plant have a set window when they will go to take meter readings. Ideally at this time, consumers will pay their bill. If the consumer is unable to do so, they are expected to come to the managing office to pay. At larger sites, there can be multiple offices where consumers are able to pay. At sites with more dispersed houses, money is collected by smaller beneficiary groups who will bring it to the managing committee. One management representative highlighted this as a problem describing their beneficiary zone as "scattered". Another respondent explained that amongst the 26 beneficiary groups, there were some that had not paid their bills for 15 months and with some of these groups more than 6 hours walk away, collecting tariffs is an extremely timely task. At 79% of sites, manager representatives answered "Yes" or "Yes, mostly" when asked if consumers paid regularly. At most sites, management representatives explained that people would be fined for late payment. The structures for this varied between a flat daily rate or a percentage of their outstanding debt. Responses from consumers suggested that this was a rare occurrence and something that they were keen to avoid due to potential social, economic and technical consequences. One respondent explains that "society shouts if [the bill is] not paid" whilst another said that "salaries will not be paid, maintenance repairs will not be on time". Managers face some difficulties in collecting tariffs, particularly at sites with dispersed consumers, but amongst consumers there is certainly a willingness to pay.

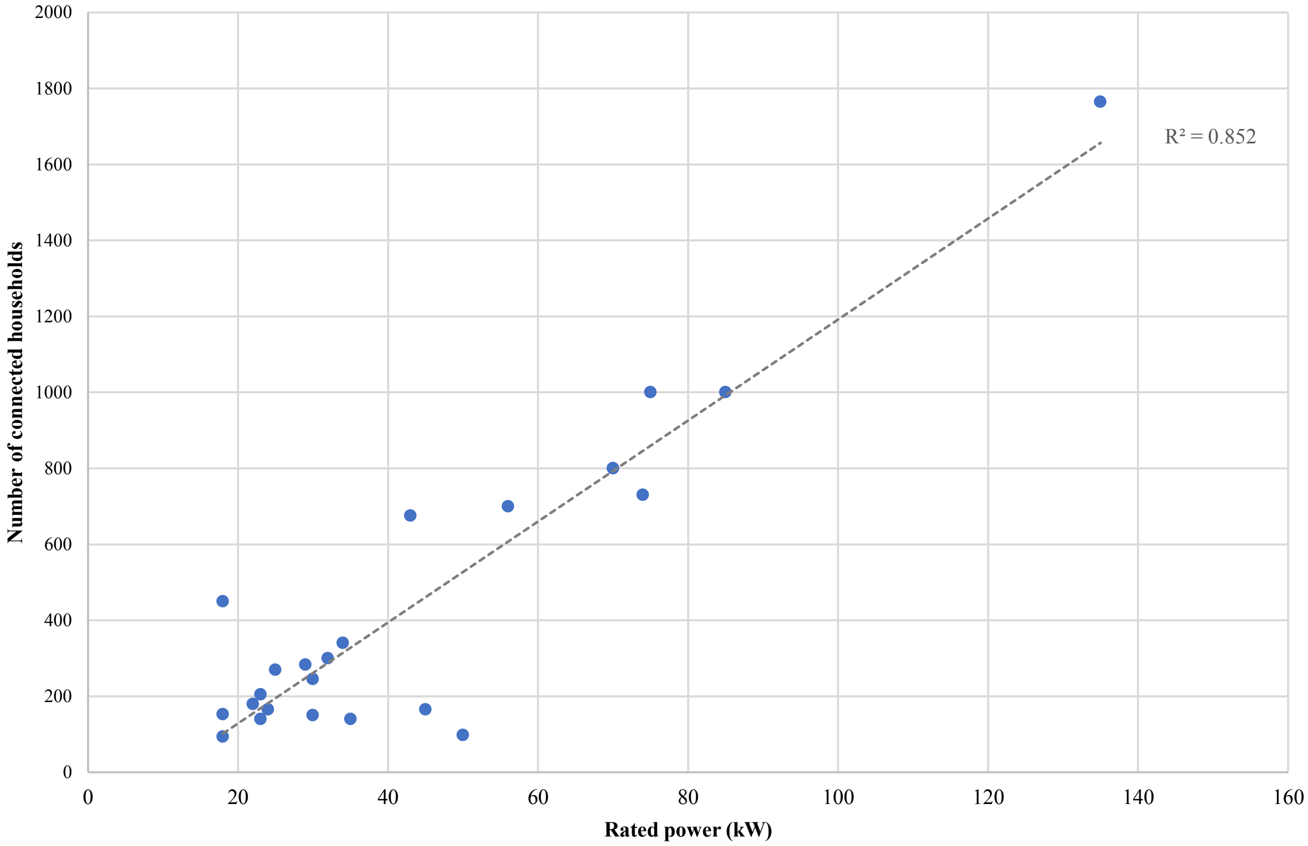

Fig. 2 Number of connected households against rated power

D. Plant usage

Sustainable plant operation depends on a combination of domestic and commercial uses. Typically, households will use most of the available electricity during the night. This means plants are more likely to be financial sustainable if they have a large number of end uses operating during the day. Fig. 2 shows the number of connected households against the rated power of each site. There is a strong positive correlation (R^2=0.852) suggesting that despite the range in rated power of the sites, the household consumption was similar at all the sites. Households are typically added until the full rated capacity of the MHP is in use. The points lying furthest above the linear line of best fit are sites that provide electricity to a large number of dispersed villages on hilltops. These areas tended to be poorer where electricity consumption is lower meaning a greater number of households can be connected. The points lying furthest below the line of best fit are located in valley areas where everyone in the local area has been connected and the cost of line extension to people living higher up is very high.

By adding information regarding the number of connected end uses, it is possible to visually assess which plants may be struggling financially. Fig. 3 shows the number of connected households against rated power, where the area of marker represents the number of end uses that are connected to that MHP. In addition, the markers are coloured according to the manager's response to the following question: "When there have been technical problems, has there been enough money to pay for repairs?" Responses to this question have been coded as "mostly yes", "sometimes yes/no" and "mostly no". If problems occur and the plant is unable to pay to repair for them, the managing committee must find alternative methods to collect the necessary money. Common approaches by managers included asking beneficiaries for additional money (either as a donation or a loan), taking banks loans or avoiding repairs until sufficient money had been saved. In the long term, it is unlikely that any of these approaches will be sustainable therefore the responses to this question are assumed to give a reasonable indication of the financial stability of each plant. The site with the highest rated power has been removed as its connection to a stone thresher with a typical load of 100kW skews the results in relation to the number of connected end uses. The line of best fit shows the relationship of both connected households and end uses to rated power. The gradient of the line of best fit indicates the relationship between rated power and number of households. The width of the line (at a given rated power) indicates the expected number of connected end uses. Both relationships are assumed to be linearly correlated to rated power with R^2 values of 0.676 and 0.465 for households and end uses respectively. There are 2 markers which overlap on the graph as they both have rated powers of 70kW, 800 connected households and a similar number of end uses.

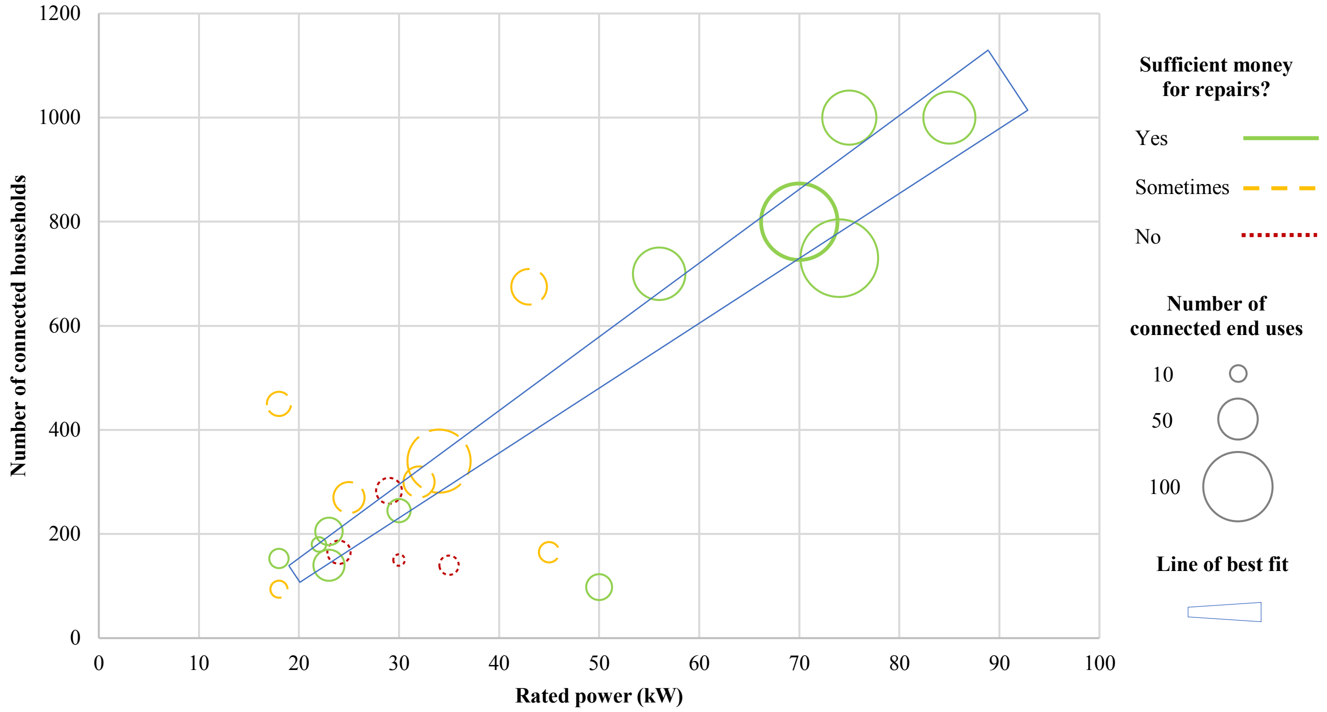

Fig. 3 Number of conneted households and end uses against rated power

The addition of the number of end uses provides a snapshot of which plants may be performing better financially in comparison to others. The vertical position relative to the line markers relative to the line of best fit can indicate whether the number of connected end uses is greater or lesser than the trend. The size of the marker relative to the width of the line of the best fit can indicate whether the number of connected end uses is greater or lesser than the trend. Considering the colour of the markers, the plants rated above 50kW tended to have less problems in paying for repairs. More commercial opportunities provide a higher non-domestic income. The larger sites were providing electricity to towns where there is also greatest demand for household connections. The higher rated capacity also permits the connection of high load uses that have a current draw which smaller MHPs would be unable to manage.

One would expect that if a site is below the line of best fit, it would struggle to pay for repairs unless it has a large number of connected end uses to generate sufficient income. This assumption is corroborated by the 2 "no" markers at 30kW and 35kW and the "sometimes" marker at 45kW. However, the "yes" marker at 50kW has a small number of household and commercial connections but has always been able to pay for repairs. The end uses connected to this site include 2 flour mills, 2 furniture makers, 2 mobile phone masts and a poultry farm. These end uses are all high load applications and are likely to be reliable customers due to a high demand for their services. For consumers, the site's tariff structure had the lowest minimum allowance of any site (NPR 100 for 4kWh), meaning most consumers would be exceeding the lower limit. Technically, this plant was very well maintained and was the only site where a professional service took place every 6 months. This combination of factors suggest that good management of a plant has put it in a financially stable position.

Sites positioned above the line of best fit can potentially afford to have fewer end uses due to their greater number of connected households. However, the "sometimes" markers at 19kW and 43kW indicate sites where this is not the case. These sites have heavily dispersed consumers whose electricity consumption may be lower. The 43kW site has consumers distributed over a wide area so that tariff collection is completed on a 6 monthly basis. Another factor of beneficiaries covering a larger geographical area is the need for longer transmission lines. The plant manager of the 19kW site explained that the transmission lines were prone to blowing down in the wind which adds an additional cost that other sites may not regularly incur. The geographical information regarding these sites helps to explain why they have experienced problems in paying for repairs.

By combining information regarding the number of connected households and ends uses with the responses of plant managers, Fig. 3 provides an impression of plants which may be struggling financially. Of the 4 sites significantly below the line of best fit, 3 had faced issues in paying for repairs. However, the graph does not account for the load of end uses connected, geographical nature of the plant nor the technical and financial management of the plant.

E. Quality of maintenance

The results of the maintenance assessment demonstrated a similar standard of maintenance at Pelton and Crossflow sites.

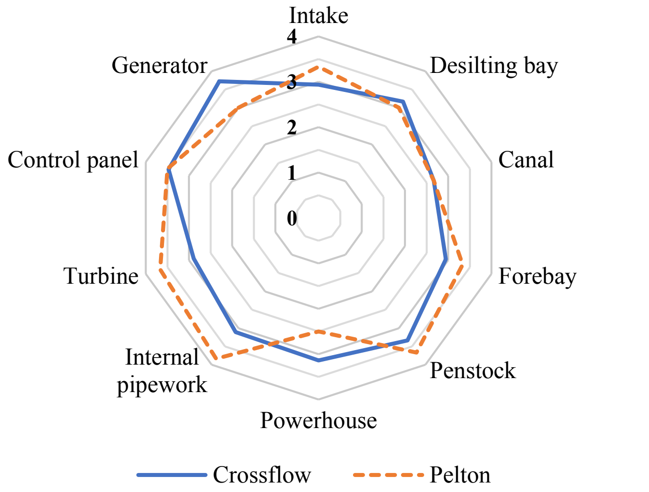

Fig. 4 Crossflow and Pelton maintenance results (out of 5) for 10 sub-systems

The mean results (out of 5) were 3.3 for Pelton turbines and 3.1 for Crossflow turbines. Fig. 4 shows a comparison between Pelton and Crossflow turbines of the average maintenance score for each of the sub-systems using a radar chart.

The largest difference was in the maintenance of the turbine sub-system, where Pelton types outperformed Crossflow types. Many of the Crossflow turbines had leakage from their casings at the shaft bore. This was less common amongst the Pelton turbines, suggesting that different sealing systems were in use. There was a similar difference for the internal pipework where leakage was more at the Crossflow sites. As Pelton turbines have smaller flow rates, leakage has more impact on power output. Less leakage in Pelton turbines suggests greater care taken by manufacturers to minimise this effect. For both turbine types, mean scores for all of the civil sub-systems received similar scores. The weakest sub-system amongst both types was the canal. Many of the canals were longer than 1km with some almost 3km long. For the operator, this results in a considerable amount of work. Often the canals are also affected by landslides or damage due to vegetation, particularly in overgrown jungle areas.

Fig. 5 shows the mean scores of sub-system assessments by site for trained (solid bars) and untrained (striped bars) operators. The vertical dashed line is the mean of all the sites. 7 of the worst 9 sites are those with untrained operators. Sites G and H are the 2 exceptions which achieved a higher standard of maintenance. Site G had a particularly good standard of maintenance inside the powerhouse. In the interview with the plant operator, it was explained that the turbine runner had been replaced 3 months ago by technicians from an engineering company which may have made it easier to preserve a good standard of maintenance since then. Site H also had a good quality of maintenance inside the powerhouse. The plant operator said that he liked his job as it was a "social contribution". Sites R and T were sites with trained operators that had a poor standard of maintenance. Both plants were connected to over 1000 households and ran for 24 hours continuously. Their operators explained that Site R stopped

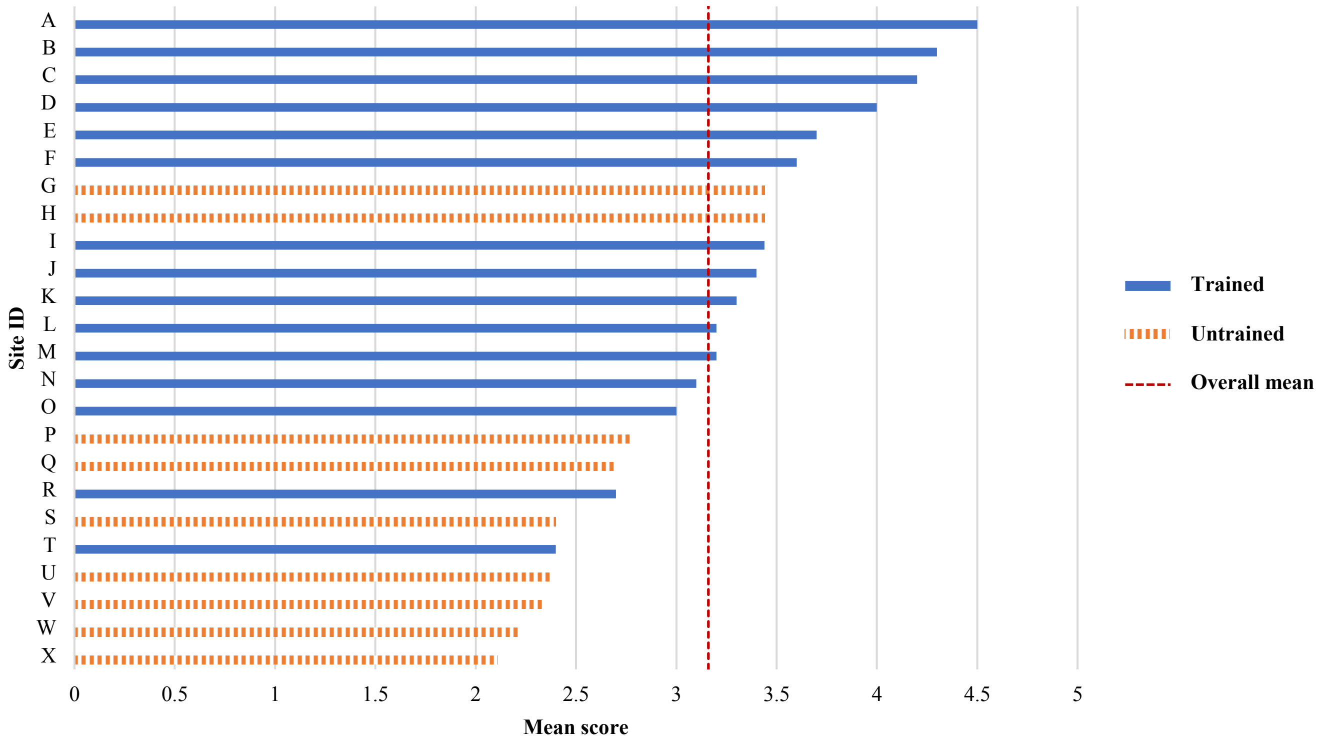

Fig. 5 Mean scores by site

TABLE IV. T-TEST RESULTS FOR TRAINED AND UNTRAINED OPERATORS

Type	Trained		Untrained		t	p
	M	*SD*	*M*	*SD*		
Overall	3.47	0.59	2.62	0.49	3.49	0.002 *
Control panel	3.93	0.80	2.72	1.03	3.22	0.004 *
Internal pipework	3.80	1.15	2.44	0.88	3.04	0.006 *
Turbine	3.47	0.99	2.44	1.13	2.32	0.030 **

*N (sample size) =24, *p<0.01, **p<0.05*

every 15-20 days for planned maintenance, and Site T not at all. Site T only had 1 operator which is insufficient for a plant of this size which is in constant operation.

An independent samples T-test was used to compare individual sub-system scores and the overall mean scores for trained and untrained operators. In this case, the T-test compares the whether the difference in the means between the two groups is significant. Table 4 shows the results that have been accepted as significantly different at the 1% and 5% confidence interval levels. In the table, *M* and *SD* are the sample mean and standard deviations respectively. Meanwhile, *t* represents the t-value which gives a corresponding *p* (p-value) which is the significance of the result. The lower the p-value, the lower the probability that the two groups could have equal means for the whole population. Therefore, the results in Table 4 demonstrate that there was a significant difference ($p<0.01$) in the sample means overall, and for the control panel and internal pipework. For the turbine sub-system, the difference in means was significant at the 5% confidence level.

At sites with untrained operators, it was found that the inside of control panels often had loose cable clamps and wires pulled from their conduits. For both the internal pipework and turbine, leakages, rust and loose bolts were common as shown in Fig. 6. All of these issues suggest a lower level of knowledge or ability and a lack of care or time. It is noticeable that the 3 sub-systems with greatest difference between the two groups are all inside

Fig. 6 Leakage from turbine casing

the powerhouse. Maintenance of civil structures was better amongst trained operators but remained a weakness for all.

F. Technical problems

There were a number of issues observed both in the powerhouse and in the civil works which resulted in low scores for maintenance. However, the initiation of these problems may have occurred at a different stage in a project's lifespan. Table 5 presents key issues affecting each of the sub-systems that were identified during observations. For each of these problems, the stages of a project where these issues can take affect have been marked.

During site visits, a commonly observed problem was poorly shaped de-silting bays and forebay tanks. The manufacturing company is responsible for the original design of de-silting bays and forebay tanks and supervises their construction. However, this supervision is often carried out by inexperienced staff and the manual labour is done by local people who are not experienced in building to precise dimensions. The outcome is that a greater amount of silt passes through the turbine which increases the wear rate of the runner, leading to the need to

TABLE V. ISSUES IDENTIFIED AT EACH SUB-SYSTEM AND THE PROJECT PHASES AFFECTED

Subsystem	Major issue (s)	Design	Manufacture	Construction	Installation	Maintenance
Intake and weir	Temporary structures require repair or reconstruction after each monsoon	•		•		•
Desilting bay	Poor shape limits settling of silt	•		•		•
Canal	Landslides make regular repair necessary			•		•
Forebay tank	Poor shape limits settling of silt	•		•		•
Penstock	Ineffective and overgrown drainage away from penstock foundations			•		•
Powerhouse	Dirty and cluttered spaces					•
Internal pipework and valves	Water leakage	•	•		•	•
Turbine	Water leakage	•	•		•	•
	Shaft and transmission belt misalignment	•	•		•	•
Control panel, cabling and ballast load	Dangerous cable routing				•	•
Generator	Transmission belt misalignment	•	•		•	•

repair or replace parts sooner. Another issue is water leakage from turbines. Turbine manufacturers are responsible for developing an effective sealing system and poor design could prevent this. Conversely, inaccurate manufacturing of a good design could also result in a leaking system. During installation, it is the responsibility of the manufacturing company to ensure that the turbine casing is properly sealed. Over time, a system may begin to leak and the operator should be responsible for preventing it by ensuring O-rings and gaskets are correctly seated and bolts are tightened. Regardless of when the problem manifests or develops, leakage results in a lower power output due to a loss in pressure. Similarly, issues with alignment (which were witnessed as large vibrations in transmission belts) can also manifest themselves in a number of stages. As a mechanical system, vibrations in the system will cause movement which alters alignment and changes the belt tension. During operation, the plant operator is responsible for correcting this issue, but it is possible that poor design and manufacture lead to it. All of the issues listed in Table 5 have an impact on the turbine when in operation and should be addressed by the operator accordingly. However, for many of these problems, greater attention to detail in an earlier stage of the project can minimise their affect. For example, manufacturing bearing housings and shafts to tolerances as recommended by the bearing supplier will minimise the possibility of shaft vibration.

IV. Conclusions

This study has found that MHPs occupy an important position in rural communities in Nepal. They deliver domestic electricity at a cheaper price than traditional forms of energy and provide a range of services to the community. These social and economic benefits combined often with a community owned structure means consumers are willing to pay their tariff and support the plant. As consumers are engaged and reliant on hydropower plants, tariffs should be set correctly to ensure there is sufficient money for operation and maintenance. Current practices of collecting money for repairs on an ad-hoc basis or by taking loans are neither the best approach for the plant nor the consumers. Further interviews will be conducted to understand how tariffs are set. In this study, it was found that larger plants had sufficient income due to their greater available power (>60kW) and location in more populated settlements; this allowed connection to a higher number of end uses and households. For economic sustainability, the training delivered to managers (particularly of smaller sites) must emphasise the importance of appropriate tariff setting and maximizing daytime loads.

Technically, this study demonstrated numerically that trained operators deliver a higher standard of maintenance than untrained operators. This information is valuable in confirming that the current training delivered to plant operators is effective. It also suggests that for long term operation of sites, a method for knowledge transfer to untrained operators needs to be found. In the small geographical area of this study, there were sites exhibiting both good and bad maintenance, experience sharing from one site to another could be used to improve standards. Many of the technical problems identified in the study can originate at an earlier stage in a project's life. Further work will investigate the complete project process by considering the design, manufacture, construction and installation stages to identify design and process changes.

V. References

[1] Nepal Micro Hydropower Development Association. MH in Nepal. [online] Available at: http://microhydro.org.np/mh-in-nepal// [Accessed 13 Jun. 2018].

[2] S.S. Khadka, and R.K. Maskey, R.K. Performance study of Micro-hydropower system in Nepal. In Sustainable Energy Technologies (ICSET), 2012 IEEE Third International Conference on (pp. 265-269). IEEE, 2012.

[3] J. Barr, Improving Maintenance of Micro Hydropower Systems in Rural Nepal–. Minor Field Study, 2013.

[4] Kumar, P., Yamashita, T., Ajoy, K., Shrestha, A. and Yadav, A., Nepal-Scaling up electricity access through mini and micro hydropower applications: a strategic stock-taking and developing a future roadmap. World Bank Publications, 2015.

[5] Alternative Energy Promotion Centre. Annual Progress Report (2010/2011). Ministry of Environment, Science and Technology, 2011.

[6] A. Harvey, Micro-Hydro Design Manual: a guide to small-scale water power schemes (No. 621.24/H341). Intermediate Technology Publications, 1993.

[7] K. Jorde and E. Hartmann, Good and bad of mini-hydro power. The ASEAN Centre for Energy, 2009.

[8] J. Butchers, S. Williamson, J. Booker, A. Tran, B. Gautam, P. Karki.. A study of micro-hydropower in Nepal: Sustainability from technical, economic and social perspectives. International Conference on Development of Renewable Energy Technology, 2018

[9] The World Bank, World Development Indicators. Mobile phone celluar subscriptions - Nepal. 2017 [Retrieved from https://data.worldbank.org/indicator/IT.CEL.SETS?end=2016&locations=NP&start=1960&view=chart]

[10] Banerjee, S.G., Singh, A. and Samad, H.A.,. Power and people: the benefits of renewable energy in Nepal. World Bank Publications, 2011